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WIND-TUNNEL INVESTIGATION OF AN NACA 0009 AIRFOIL WITH 0.25- AND 0.50-AIRFOIL-CHORD PLAIN FLAPS TESTED INDEPENDENTLY AND IN COMBINATION

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SUMMARY

Wind-tunnel tests have been made to determine the aerodynamic section characteristics of an NACA 0009 airfoil with plain flaps 25 and 50 percent of the airfoil chord. The flaps were tested independently and in combination.

Results of the investigation indicated that the larger flap would provide greater lift increments but would lose lift effectiveness at the higher deflections and at a lower angle of attack than would the smaller flap. The hinge-moment and lift-effectiveness parameters for each flap indicated good agreement with curves predicting the variation of these parameters with flap chord.

Although the effect of sealing the gap was small, it generally increased the lift effectiveness and the lift-curve slope.

Theoretical calculations of aerodynamic characteristics made by the use of parameters measured in the present investigation indicated close agreement with calculations made by the use of parameters estimated from pressure-distribution data for a model having similar flaps that were linked to give balance.

INTRODUCTION

An extensive investigation of control-surface characteristics is being conducted by the Langley Laboratory of the National Advisory Committee for Aeronautics that includes several types of flaps of various chords.

Among the control surfaces included in the investigation is a 25-percent-airfoil-chord control flap with a trimming and balancing flap having a chord twice the control-flap chord, or a 50 percent airfoil chord, that is linked to give hinge-moment balance with angle of attack and flap deflection (reference 1). In order to calculate the characteristics for this arrangement, it was necessary to obtain the rate of change of control-flap hinge-moment coefficient with trim-flap deflection and the rate of change of trim-flap hinge-moment coefficient with control-flap deflection – as well as the lift effectiveness, the rate of change of hinge-moment coefficient with deflection, and the rate of change of hinge-moment coefficient with angle of attack for both the control flap and the trim flap independently. These parameters were all estimated from pressure-distribution data of reference 2 since no data were available for 25-percent-airfoil-chord and 50-percent-airfoil-chord flaps.

The purpose of the present investigation is to determine the aerodynamic characteristics of 25-percent-airfoil-chord and 50-percent-airfoil-chord plain flaps independently and in combination and thus to provide a check on the parameters calculated from reference 2.

COEFFICIENTS AND SYMBOLS

The coefficients and symbols used are defined as follows:

c_l airfoil section lift coefficient (l/qc)

c_h flap section hinge-moment coefficient $\left(h/qc_f^2\right)$

$c_{h_{f_{25}}}$ 0.25c-flap section hinge-moment coefficient $\left(\dfrac{h_{f_{25}}}{qc_{f_{25}}^2}\right)$

$c_{h_{f_{50}}}$ 0.50c-flap section hinge-moment coefficient $\left(\dfrac{h_{f_{50}}}{qc_{f_{50}}^2}\right)$

where

l airfoil section lift

$h_{f_{25}}$ 0.25c-flap section hinge moment about 0.25c-flap hinge axis

$h_{f_{50}}$ 0.50c-flap section hinge moment about 0.50c-flap hinge axis

q dynamic pressure

c chord of basic airfoil

c_f flap chord

$c_{f_{25}}$ 0.25c flap chord

$c_{f_{50}}$ 0.50c flap chord

and

α_o angle of attack for airfoil of infinite aspect ratio

δ_f flap deflection

$\delta_{f_{25}}$ deflection of 0.25c flap with respect to airfoil when used independently, with respect to 0.50c flap when used in combination with 0.50c flap

$\delta_{f_{50}}$ deflection of 0.50c flap with respect to airfoil

and

$$c_{l_\alpha} = \left(\frac{\partial c_l}{\partial \alpha_o}\right)_{\delta_f}$$

$$c_{l_\delta} = \left(\frac{\partial c_l}{\partial \delta_f}\right)_{\alpha_o}$$

$$\alpha_\delta = \left(\frac{\partial \alpha_o}{\partial \delta_f}\right)_{c_l}$$

$$c_{h_\alpha} = \left(\frac{\partial c_h}{\partial \alpha_o}\right)_{\delta_f}$$

$$c_{h_\delta} = \left(\frac{\partial c_h}{\partial \delta_f}\right)_{\alpha_o}$$

$$c_{h_{25}\delta_{50}} = \left(\frac{\partial c_{h_{f_{25}}}}{\partial \delta_{f_{50}}}\right)_{\alpha_o, \delta_{f_{25}}}$$

$$c_{h_{50}\delta_{25}} = \left(\frac{\partial c_{h_{f_{50}}}}{\partial \delta_{f_{25}}}\right)_{\alpha_o, \delta_{f_{50}}}$$

$$\frac{dc_h}{d\alpha_o} = \frac{\partial c_{h_{f_{25}}}}{\partial \alpha_o} + \frac{\partial c_{h_{f_{50}}}}{\partial \alpha_o}\left(\frac{c_{f_{50}}}{c_{f_{25}}}\right)^2 \frac{\partial \delta_{f_{50}}}{\partial \delta_{f_{25}}}$$

$$\frac{d\alpha_o}{d\delta_f} = \frac{\partial \alpha_o}{\partial \delta_{f_{25}}} + \frac{\partial \alpha_o}{\partial \delta_{f_{50}}} \frac{\partial \delta_{f_{50}}}{\partial \delta_{f_{25}}}$$

$$\frac{dc_h}{d\delta_f} = \frac{\partial c_{h_{f_{25}}}}{\partial \delta_{f_{25}}} + \left(\frac{c_{f_{50}}}{c_{f_{25}}}\right)^2 \frac{\partial \delta_{f_{50}}}{\partial \delta_{f_{25}}}\left(\frac{\partial c_{h_{f_{50}}}}{\partial \delta_{f_{50}}} \frac{\partial \delta_{f_{50}}}{\partial \delta_{f_{25}}} + \frac{\partial c_{h_{f_{50}}}}{\partial \delta_{f_{25}}}\right) + \frac{\partial c_{h_{f_{25}}}}{\partial \delta_{f_{50}}} \frac{\partial \delta_{f_{50}}}{\partial \delta_{f_{25}}}$$

The subscripts 25 and 50 refer to the 0.25c flap and the 0.50c flap.

APPARATUS AND MODEL

The 2-foot-chord by 4-foot-span model (fig. 1) was tested in the Langley 4- by 6-foot vertical tunnel described in reference 3. The model was made of laminated mahogany to the NACA 0009 profile and was equipped with two plain flaps having chords 25 percent of the airfoil chord (0.25c) and 50 percent of the airfoil chord (0.50c), respectively. Both flaps had nose gaps 0.005c in width.

Flap hinge moments were measured by electrical strain gages. Lift, drag, and pitching moment were measured with a three-component balance; but since drag and pitching moment were not of primary importance in this investigation, their values are not presented.

Test Procedure

The tests were made at a dynamic pressure of 13 pounds per square foot, which corresponds to a velocity of about 71 miles per hour under standard conditions. The effective Reynolds number for maximum lift coefficients for these tests was approximately 2.58×10^6. (Effective Reynolds number = test Reynolds number × turbulence factor. The turbulence factor for the Langley 4- by 6-foot vertical tunnel is 1.93.)

The airfoil model when mounted in the tunnel completely spanned the test section. With this type of installation, two-dimensional flow is approximated and section characteristics of the model can be determined.

Tests of the 0.25c flap used independently were made with the 0.50c flap strapped at zero deflection and its gap faired to the airfoil contour. For the tests of the 0.50c flap used independently, the 0.25c flap was strapped at zero deflection and its gap faired to the airfoil contour. Tests of the 0.25c flap and the 0.50c flap used independently were made through a flap-deflection range of 30° with gap sealed but unfaired and through a range of 10° for open gap.

Tests of the flaps in combination were made with the 0.50c flap restrained by strain gages to the main airfoil and the 0.25c flap restrained by strain gages to the 0.50c flap. In this manner, simultaneous hinge-moment readings could be made for each flap. The parameter $c_{h_{25_{\delta_{50}}}}$ was obtained by setting the 0.25c flap to zero deflection and deflecting the 0.50c flap through a range of 10° with hinge-moment readings recorded for both flaps. The parameter $c_{h_{50_{\delta_{25}}}}$ was obtained in a like manner by deflecting the 0.25c flap through a range of 10° with the 0.50c flap set at zero deflection. These tests were made with open and with sealed gaps.

All tests were made through the angle-of-attack range from zero to negative stall and from zero to positive stall.

Corrections

An experimentally determined tunnel correction was applied to the lift. The angle of attack and hinge moments were corrected for the effect of streamline curvature induced by the tunnel walls in accordance with a theoretical analysis similar to that presented in reference 4 for finite-span models.

The tunnel-wall corrections were applied in the following manner: for the 0.25c flap,

$$\alpha_o = \alpha_{o_T} + \left(0.21c_{l_T} - 0.16c_{l_{T_f}}\right)$$

$$c_h = c_{h_T} + 0.00676c_{l_T}$$

for the 0.50c flap,

$$\alpha_o = \alpha_{o_T} + \left(0.21c_{l_T} - 0.076c_{l_{T_f}}\right)$$

$$c_h = c_{h_T} + 0.00876c_{l_T}$$

and for both the 0.25c and 0.50c flaps,

$$c_l = \left(0.965 - \left|0.007\ c_{l_T}\right|\right)c_{l_T}$$

where

α_{o_T} measured angle of attack

c_{l_T} measured lift coefficient

$c_{l_{T_f}}$ measured lift-coefficient increment caused by flap deflection (measured arbitrarily at $\alpha_{o_T} = -8^{\circ}$)

c_{h_T} measured hinge-moment coefficient

DISCUSSION

The 0.25c and 0.50c Plain Flaps Tested Independently

Lift.- The lift-characteristics for the 0.25c flap are presented in figure 2 for open gap and figure 3 for sealed gap. The lift characteristics for the 0.50c flap are presented in figures 4 and 5 for open and sealed gaps, respectively. The lift parameters are presented in table I.

The lift curves for the 0.25c flap are fairly linear through a flap deflection of 20° (fig. 3). For the 0.50c flap the lift curves are fairly linear through a flap deflection of 15° but become increasingly nonlinear in the higher lift range and at greater flap deflections (fig. 4). The greater nonlinearity of the lift curves for the larger flap is probably caused by air-flow separation that results from the break in the airfoil contour at the 0.50c station when the flap is deflected. For each flap when the angle of attack and flap deflection are of opposite sign, a higher angle of attack is reached before stalling than when the angle of attack and flap deflection are of the same sign.

The effectiveness of the 0.25c flap in producing lift begins to decrease throughout the angle-of-attack range for deflections beyond 20°. The 0.50c flap provides larger increments of lift than the 0.25c flap but begins to lose effectiveness when deflected 15°, and the loss of effectiveness becomes more apparent as the flap is deflected farther. This loss of effectiveness for both flaps is probably caused by a stall beginning at the trailing edge of the airfoil and spreading forward over the deflected flaps.

The lift-effectiveness parameter α_{δ} for both flaps shows good agreement with curves predicting the variation of α_{δ} with flap chord as shown originally in reference 2 and in modified form in reference 5. (See fig. 6.) Sealing the gaps generally increased the effectiveness α_δ for both flaps.

Hinge moments.– Hinge-moment characteristics for open and sealed gaps are presented for the 0.25c flap in figures 2 and 3 and for the 0.50c flap in figures 4 and 5. The hinge-moment parameters are presented in table I.

The general trend of the hinge-moment curves is that which would be expected for plain flaps on an NACA 0009 airfoil. Airfoil stall is accompanied by a rapid increase in hinge-moment coefficient. Air-flow separation over the flaps causes the hinge-moment curves to become nonlinear and sometimes to reverse slope.

Curves showing the variation of hinge-moment parameters c_{h_α} and c_{h_δ} with flap chord are given in references 2 and 5. The inclusion on these curves of the hinge-moment parameters for the 0.25c and 0.50c flaps indicates that these parameters are in agreement with the general trend of the curves (fig. 6).

Sealing the gap provided a negative increase in c_{h_α} and c_{h_δ} for both flaps.

The 0.25c and 0.50c Plain Flaps Tested in Combination

Effect on lift.– The lift characteristics of the airfoil with the 0.25c and 0.50c flaps used in combination are presented in figures 7 and 8 for open gaps and in figures 9 and 10 for sealed gaps. The lift parameters are presented in table II.

The lift-curve slope c_{l_α} for open gaps is less than that for either the 0.25c flap or 0.50c flap alone with open gap. This loss would be expected since there is a gap at both the 0.50c station and the 0.75c station. With the gaps sealed, c_{l_α} is the same as for the 0.50c flap with sealed gap and slightly less than the 0.25c flap with sealed gap. This slight difference is probably caused by the decreased rigidity of the model when both flaps are restrained by strain gages.

The lift-effectiveness parameter α_δ for each flap was less than for the flaps when used independently, because of the decrease in c_{l_δ} resulting from the decreased rigidity of the model.

Effect on hinge moment.– The hinge-moment characteristics of the airfoil with the 0.25c and 0.50c flaps used in combination are presented in figures 7 and 8 for open gaps and in figures 9 and 10 for sealed gaps, and the hinge-moment parameters are listed in table II.

For either flap the hinge moment caused by deflection c_{h_δ} is slightly less when the flaps are used in combination than when used independently. This reduction would be expected since deflecting either flap would create forces tending to cause opposite deflection of the other flap, which tendency would result in a balancing moment as is the case for a balancing tab.

The hinge moment of the 0.50c flap caused by a deflection of the 0.25c flap is fairly large since the deflection of the 0.25c flap produces an increase in the resultant pressure coefficient over the rear of the airfoil. This increase results in a large moment when referred to the hinge line of the 0.50c flap. The hinge moment of the 0.25c flap resulting from a deflection of the 0.50c flap is comparatively small since the resultant pressure coefficient caused by deflecting the 0.50c flap is quite small over the 0.25c flap. This hinge moment is approximately the same as that caused by a change in the angle of attack.

Comparison of Experimentally Determined Data with Theoretically Calculated Data

Data are presented in reference 1 for a 0.25c plain control flap linked with a trim flap having a chord twice the control-flap chord or 0.50c. Theoretical calculations of the aerodynamic characteristics of this type of flap arrangement as determined from pressure-distribution data are also presented in reference 1.

By the use of the parameters $c_{h_{50_{\delta_{25}}}}$, $c_{h_{25_{\delta_{50}}}}$, α_δ, c_{h_δ}, and c_{h_α} obtained experimentally in the present paper, it is possible to compute the characteristics of a 0.25c control flap with a 0.50c trim flap for any linkage ratio and thus to provide a check for the data of references 1 and 2. The results of this comparison are shown in figure 11 and indicate that the values obtained by the use of parameters from force-test data are in close agreement with the values obtained by the use of parameters from the pressure-distribution data of reference 2.

CONCLUSIONS

From tests made of an NACA 0009 airfoil with 0.25- and 0.50-airfoil-chord plain flaps operated independently and in combination, the following conclusions were indicated:

1. Larger increments of lift were provided by the larger flap although it began to lose lift effectiveness at the higher deflections and at lower angles of attack than did the smaller flap.

2. The effect of sealing the gap was small but generally increased the lift effectiveness and the lift-curve slope.

3. The hinge-moment and lift-effectiveness parameters for each flap indicated close agreement with curves predicting the variation of these parameters with flap chord for plain flaps.

4. Theoretical calculations of the aerodynamic characteristics of a 0.25-chord plain control flap with a 0.50-chord trim flap made by the use of hinge-moment parameters measured in the present investigation are in close agreement with results calculated by the use of parameters obtained from pressure-distribution data.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., November 3, 1947

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3. Ames, Milton B., Jr., and Sears, Richard I.: Pressure-Distribution Investigation of an N.A.C.A. 0009 Airfoil with a 30-Percent-Chord Plain Flap and Three Tabs. NACA TN No. 759, 1940.

4. Swanson, Robert S., and Toll, Thomas A.: Jet-Boundary Corrections for Reflection-Plane Models in Rectangular Wind Tunnels. NACA Rep. No. 770, 1943.

5. Tamburello, Vito, Smith, Bernard J., and Silvers, H. Norman: Wind-Tunnel Investigation of Control-Surface Characteristics of Plain and Balanced Flaps on an NACA 0009 Elliptical Semispan Wing. NACA ARR No. L5L18, 1946.

TABLE I

PARAMETERS FOR 0.25c AND 0.50c PLAIN FLAPS

TESTED INDEPENDENTLY ON AN NACA 0009 AIRFOIL

c_f/c	Gap	c_{l_α}	c_{l_δ}	α_δ	c_{h_α}	c_{h_δ}
0.25	0.005c	0.092	0.045	-0.49	-0.0067	-0.0118
.25	Sealed	.095	.048	-.50	-.0070	-.0120
.50	.005c	.090	.064	-.71	-.0121	-.0148
.50	Sealed	.094	.071	-.75	-.0123	-.0155

TABLE II

PARAMETERS FOR 0.25c AND 0.50c PLAIN FLAPS TESTED

IN COMBINATION ON AN NACA 0009 AIRFOIL

Gap	c_{l_α}	$c_{l_{\delta_{25}}}$	$c_{l_{\delta_{50}}}$	$\alpha_{\delta_{25}}$	$\alpha_{\delta_{50}}$	$c_{h_{\alpha_{25}}}$	$c_{h_{\alpha_{50}}}$	$c_{h_{\delta_{25}}}$	$c_{h_{\delta_{50}}}$	$c_{h_{50_{\delta_{25}}}}$	$c_{h_{25_{\delta_{50}}}}$
0.005c	0.089	0.039	0.058	-0.43	-0.68	-0.0072	-0.0119	-0.0110	-0.0141	-0.0202	-0.0066
Sealed	.093	.045	.066	-.49	-.72	-.0068	-.0120	-.0108	-.0144	-.0208	-.0060

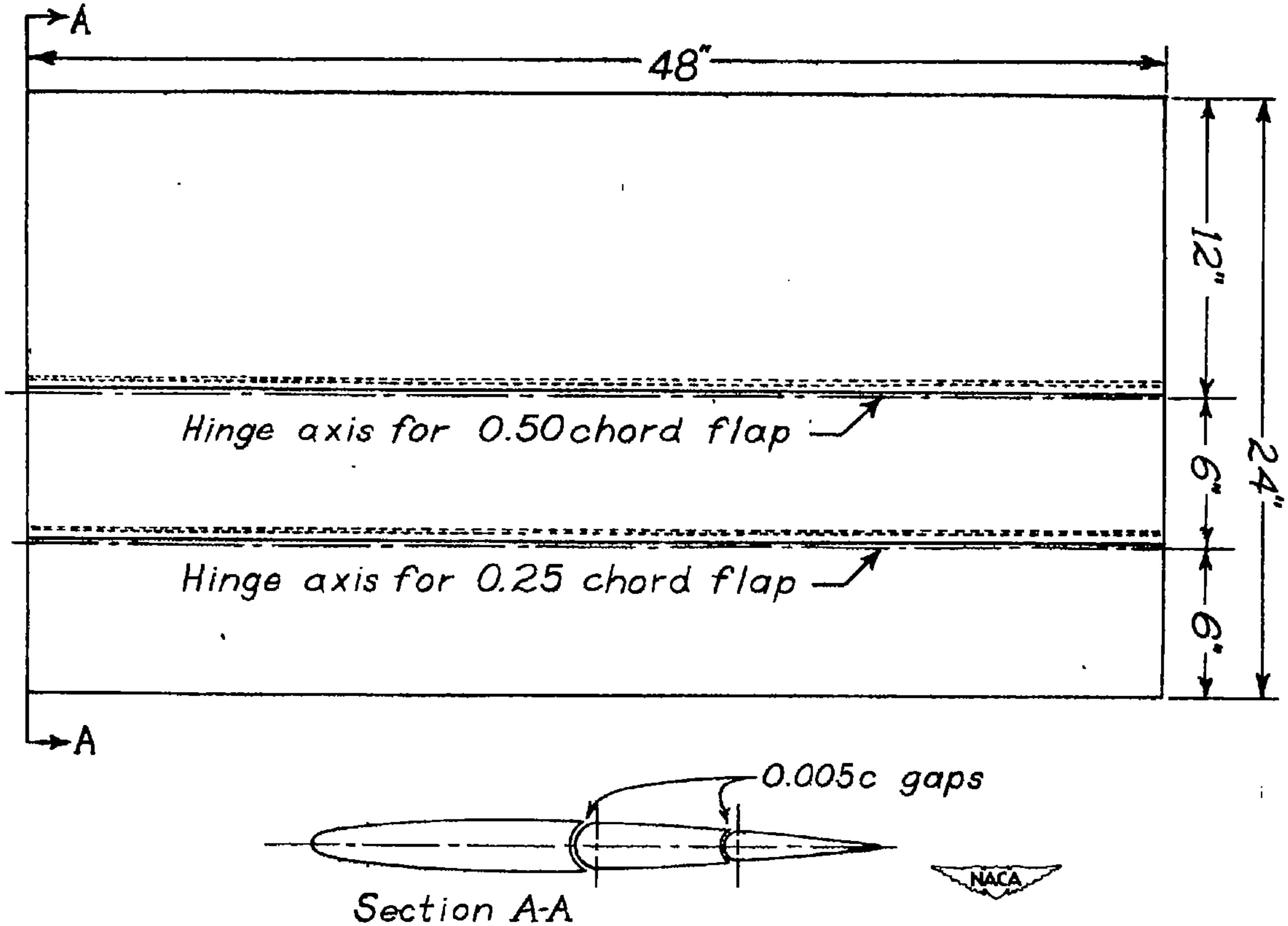


Figure 1 - Details of NACA 0009 model with 0.25c and 0.50c plain flaps.

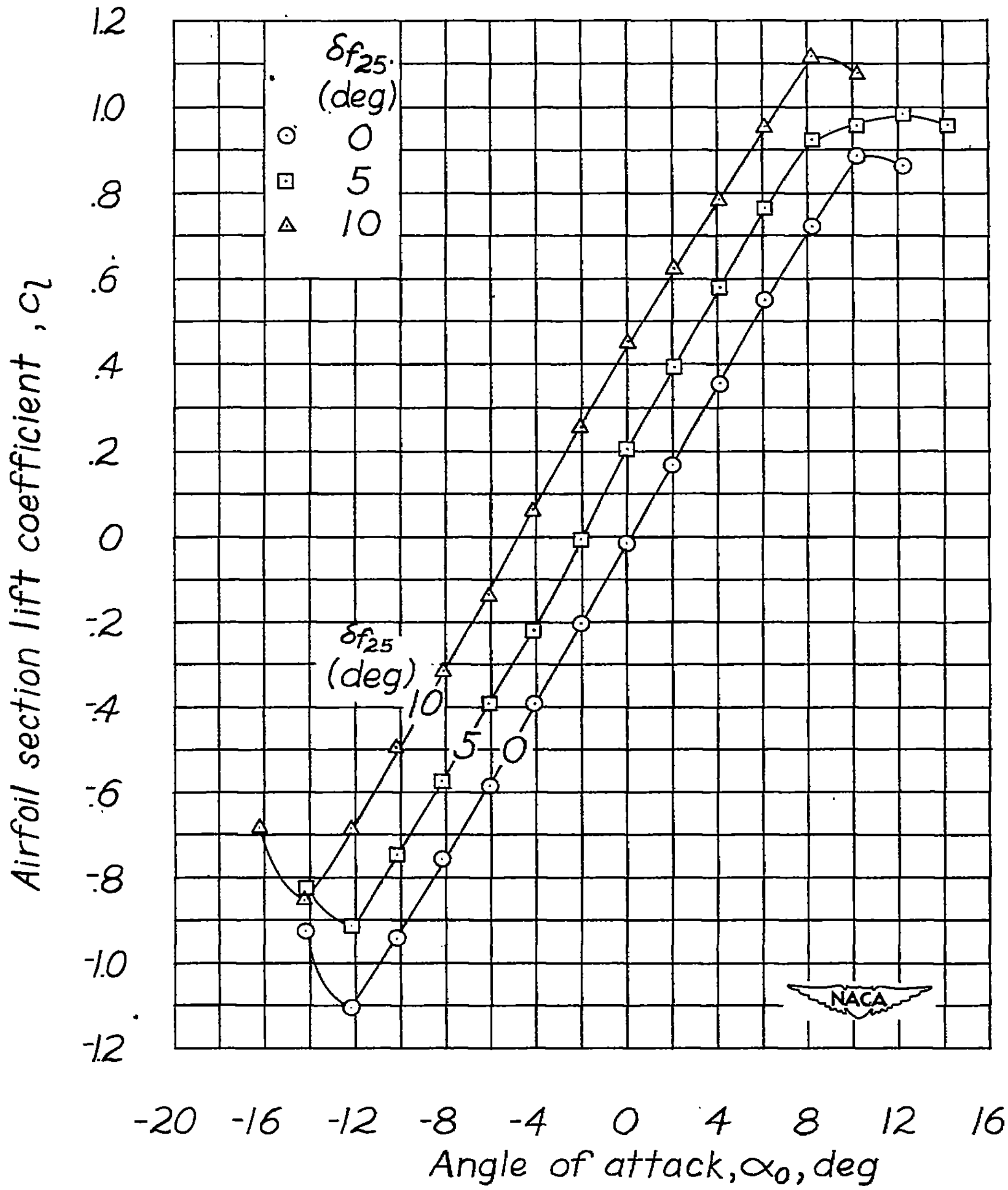


Figure 2 .- Aerodynamic section characteristics of an NACA 0009 airfoil with a 0.25c plain flap and 0.005c gap.

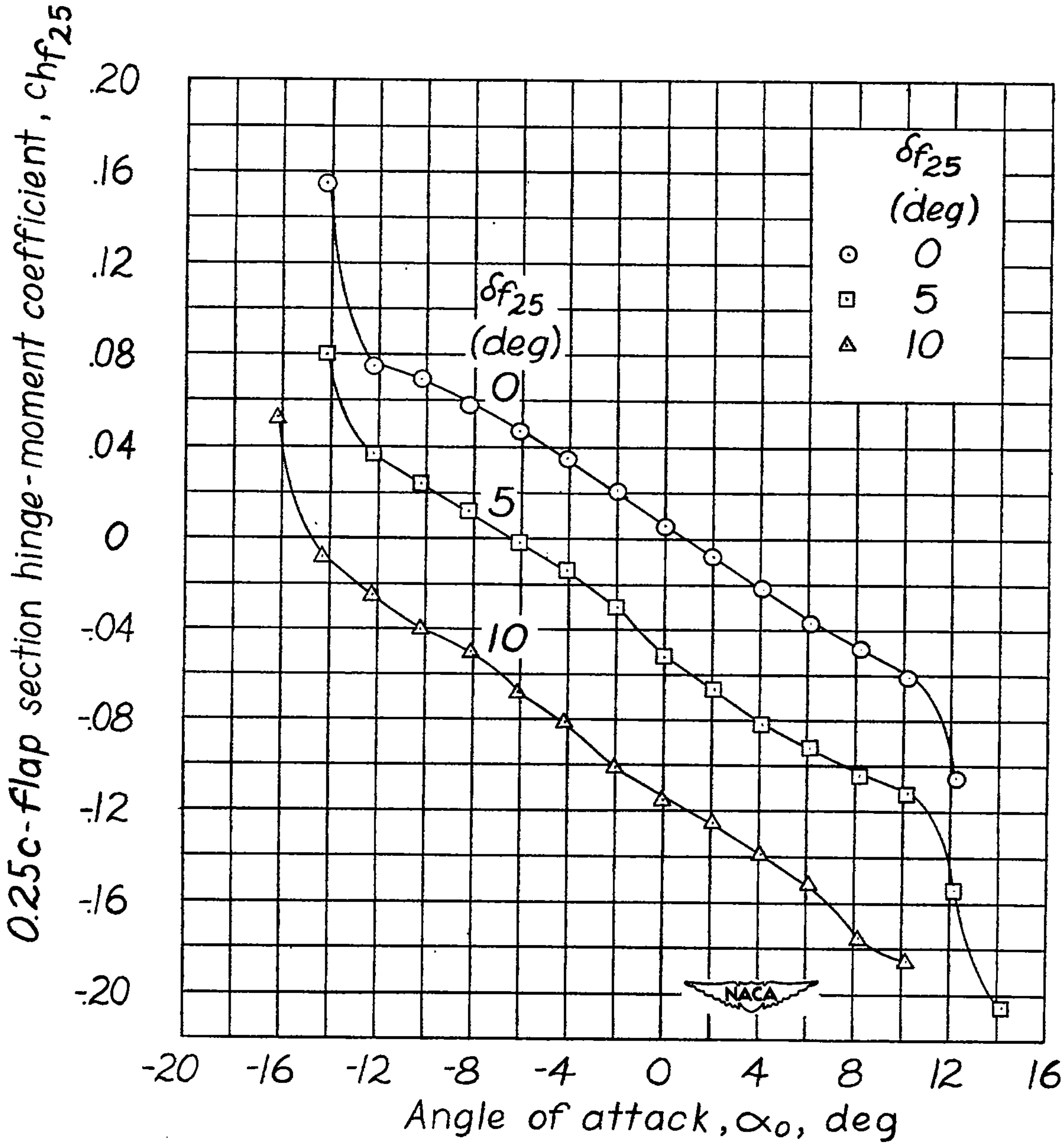


Figure 2.- Concluded.

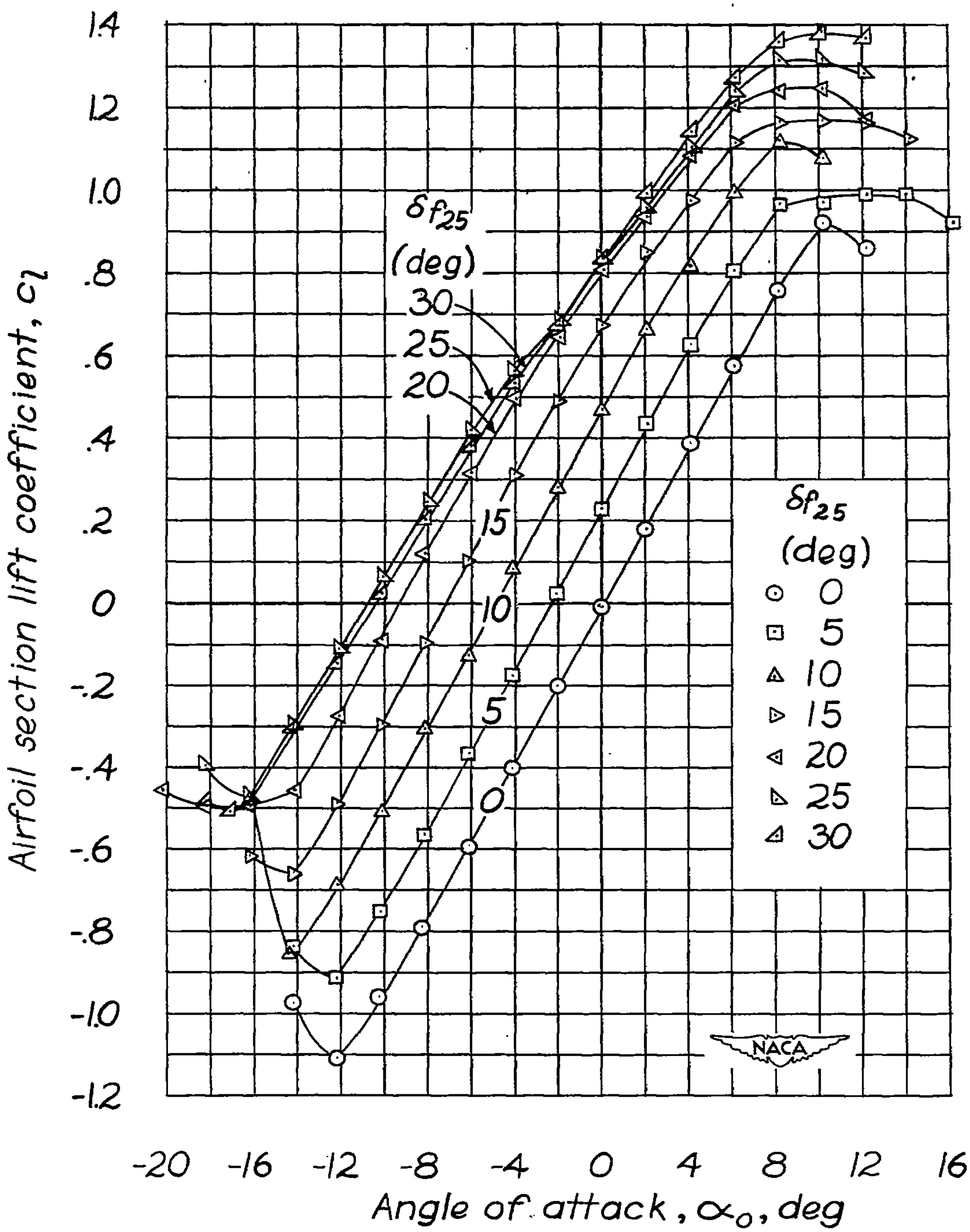


Figure 3.- Aerodynamic section characteristics of an NACA 0009 airfoil with a 0.25c plain flap and sealed gap.

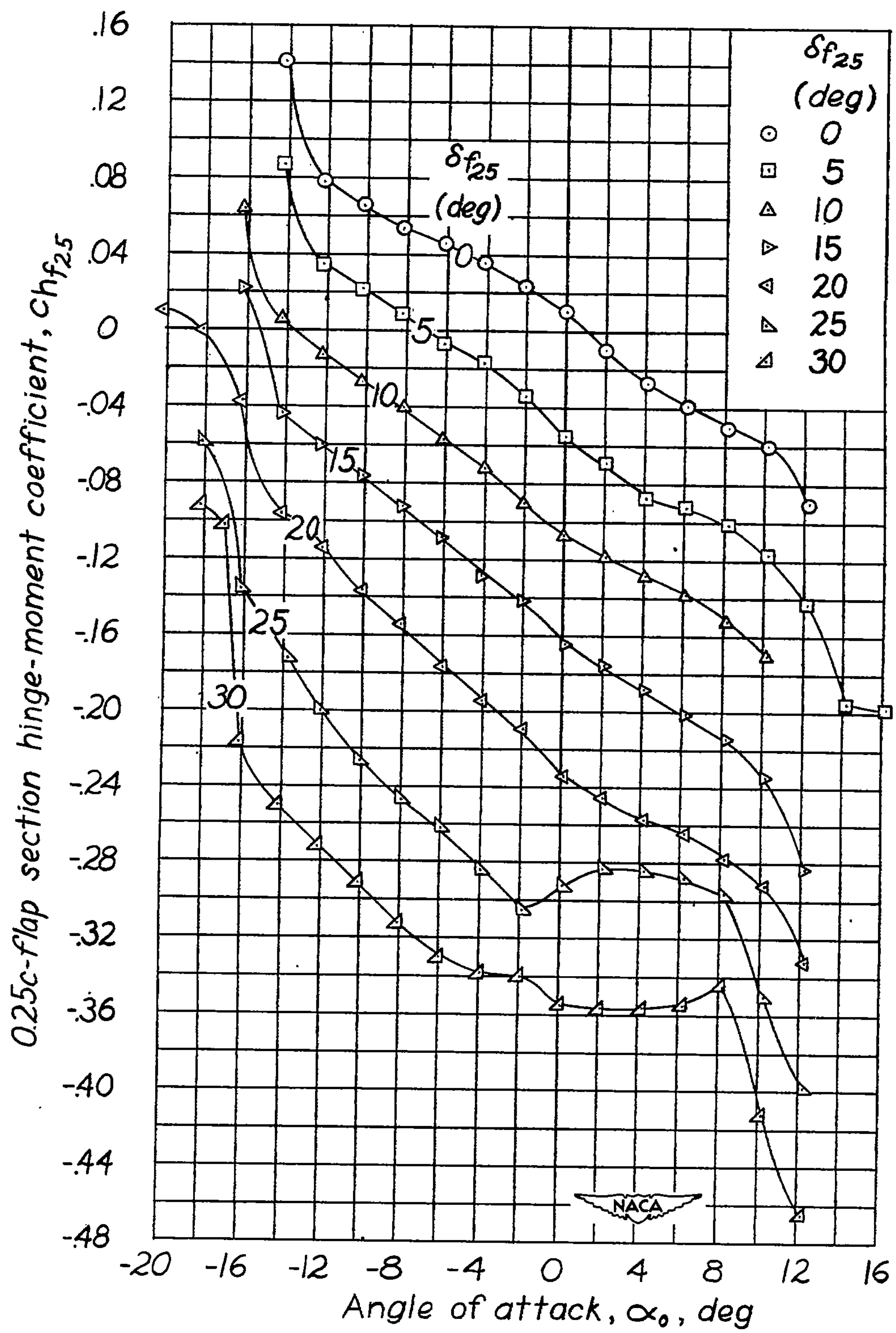


Figure 3.- Concluded.

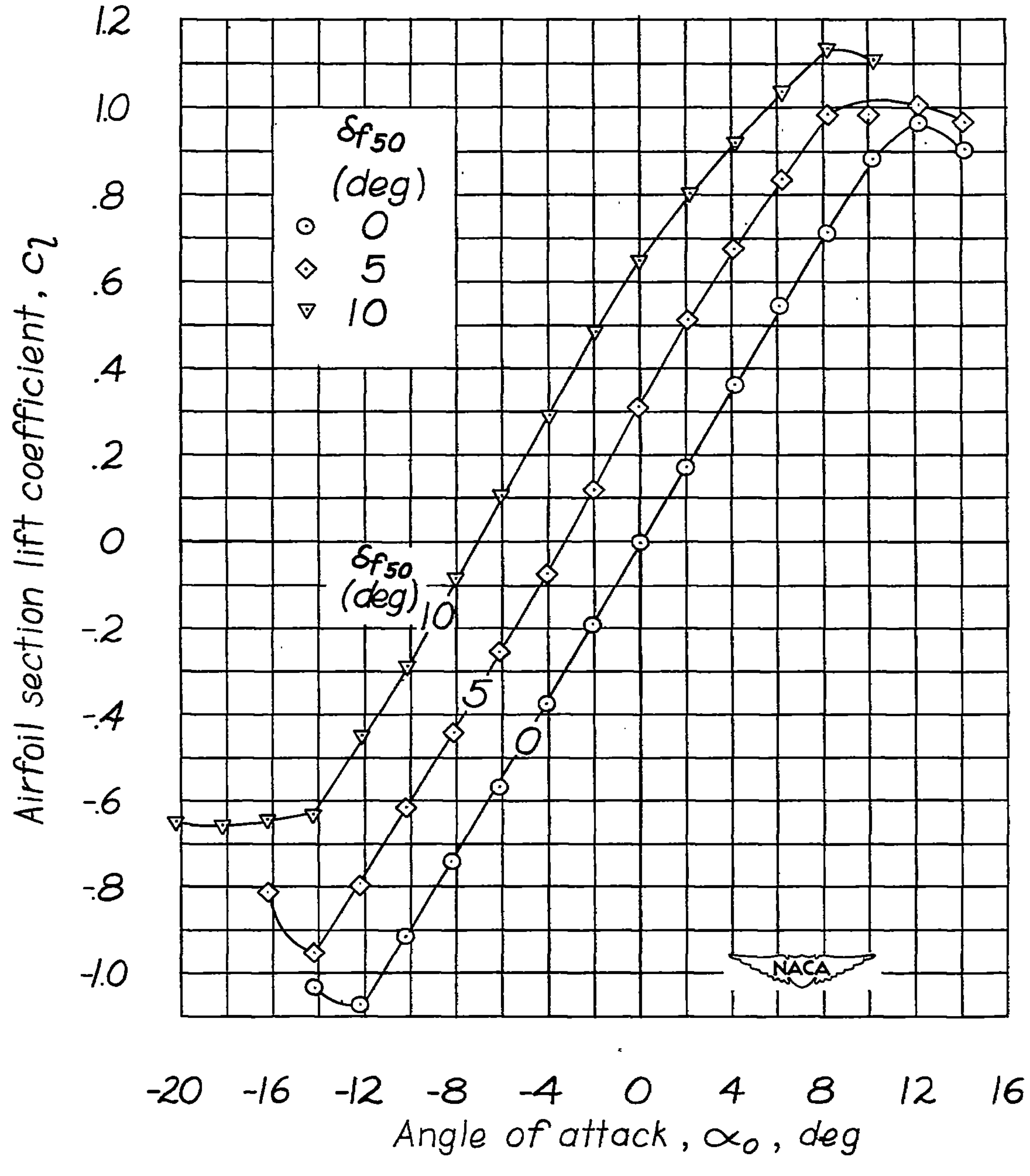


Figure 4.- Aerodynamic section characteristics of an NACA 0009 airfoil with a 0.50c plain flap and 0.005c gap.

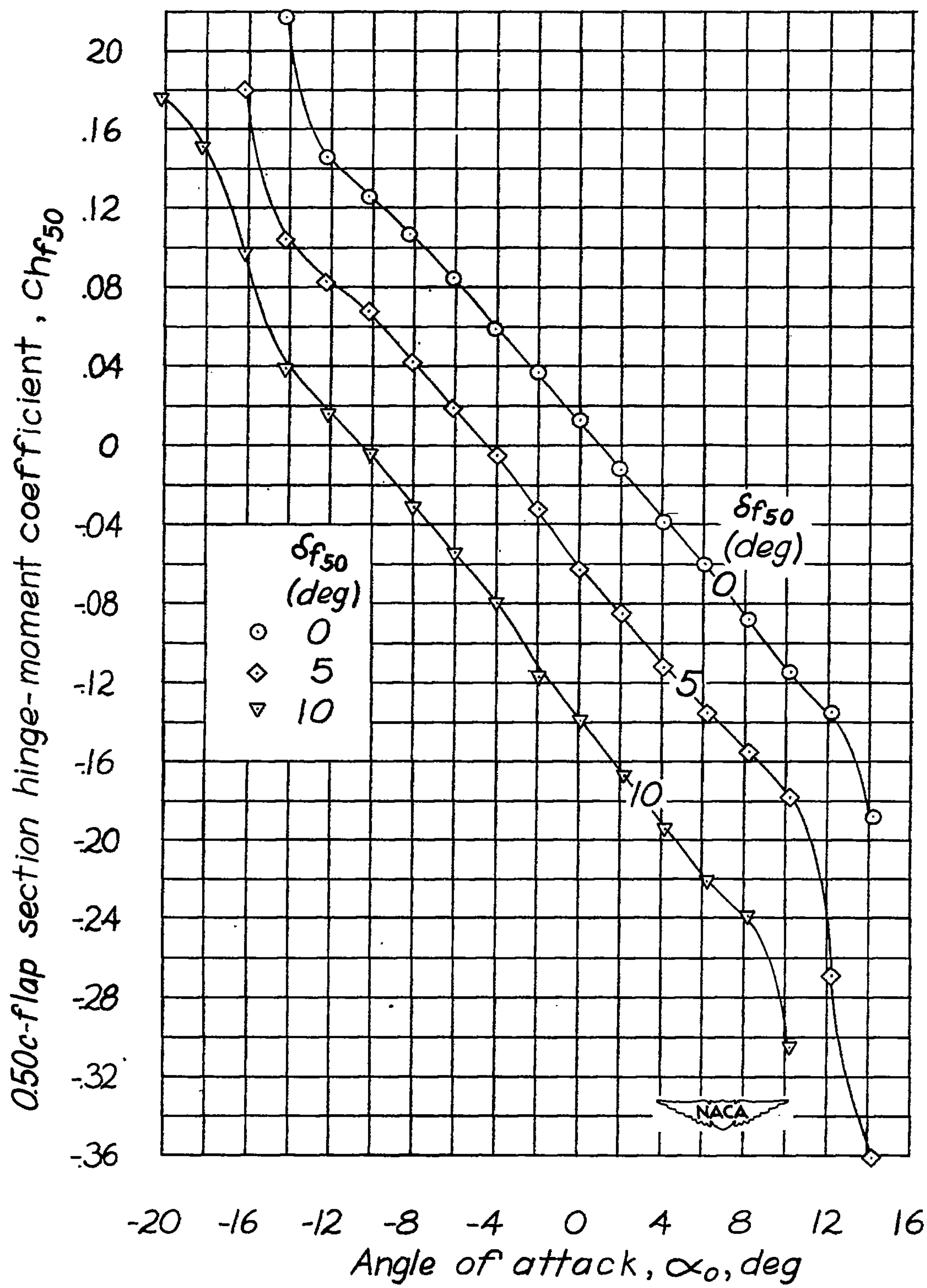


Figure 4.- Concluded.

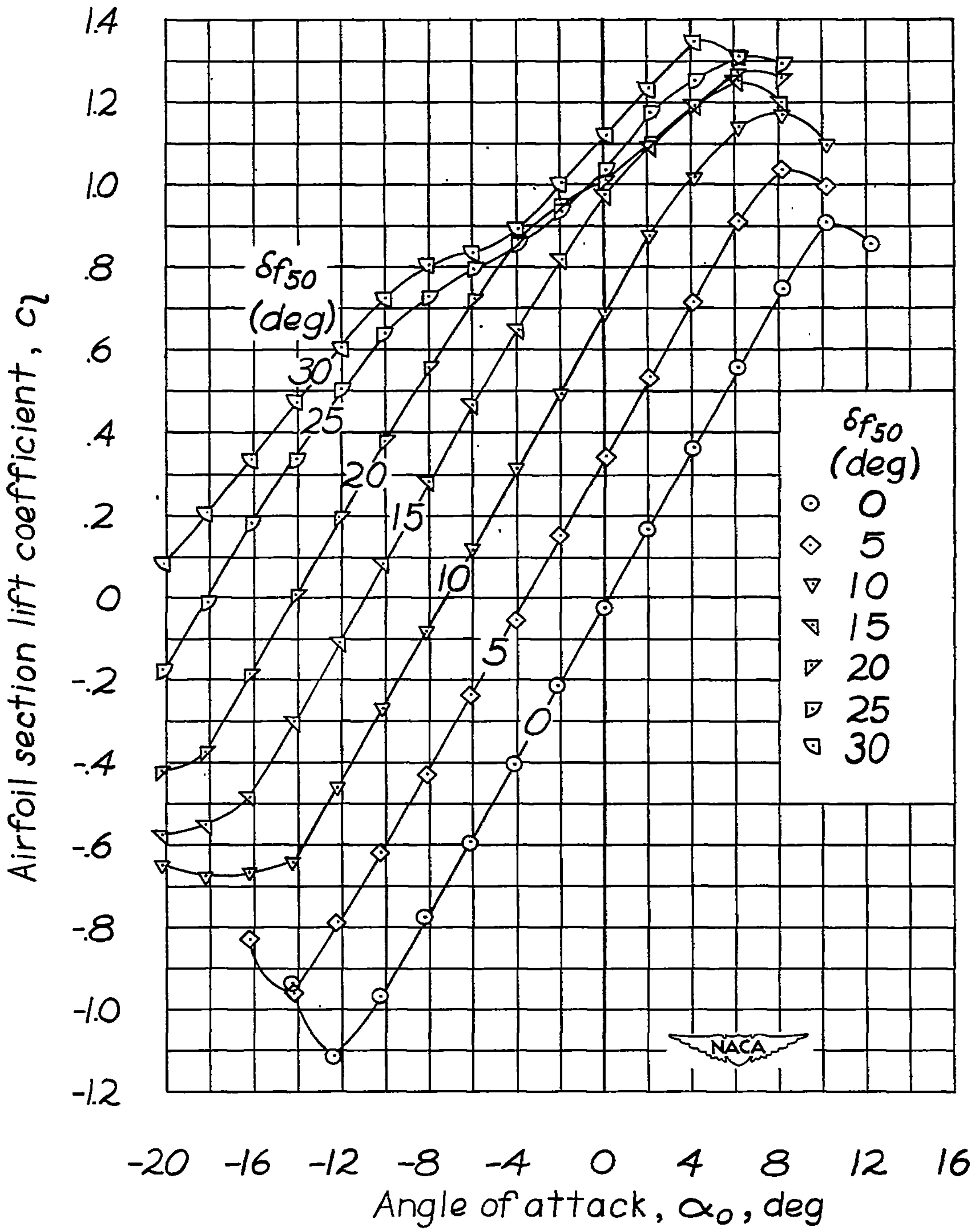


Figure 5.- Aerodynamic section characteristics of an NACA 0009 airfoil with a 0.50c plain flap and sealed gap.

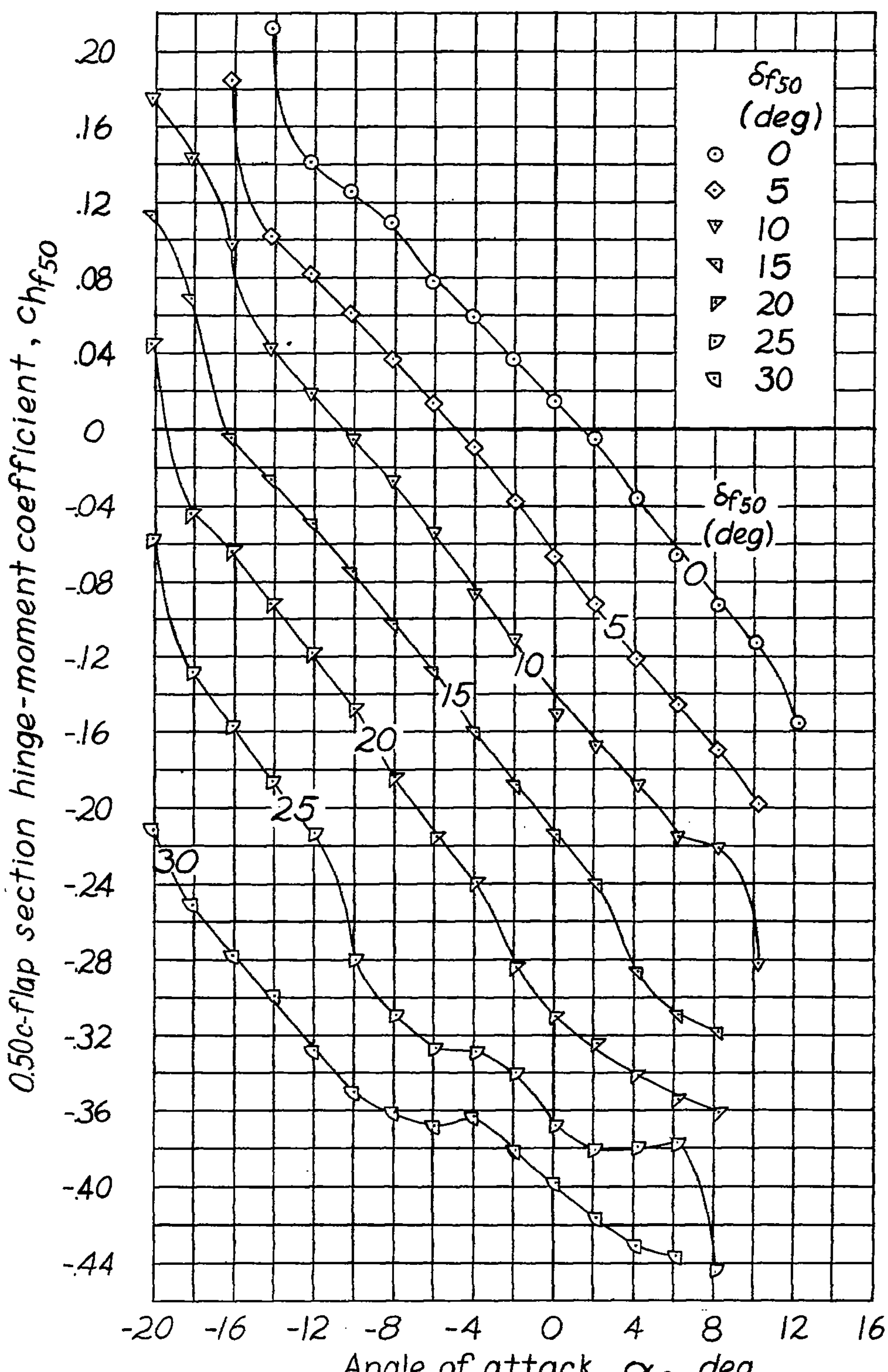


Figure 5.- Concluded.

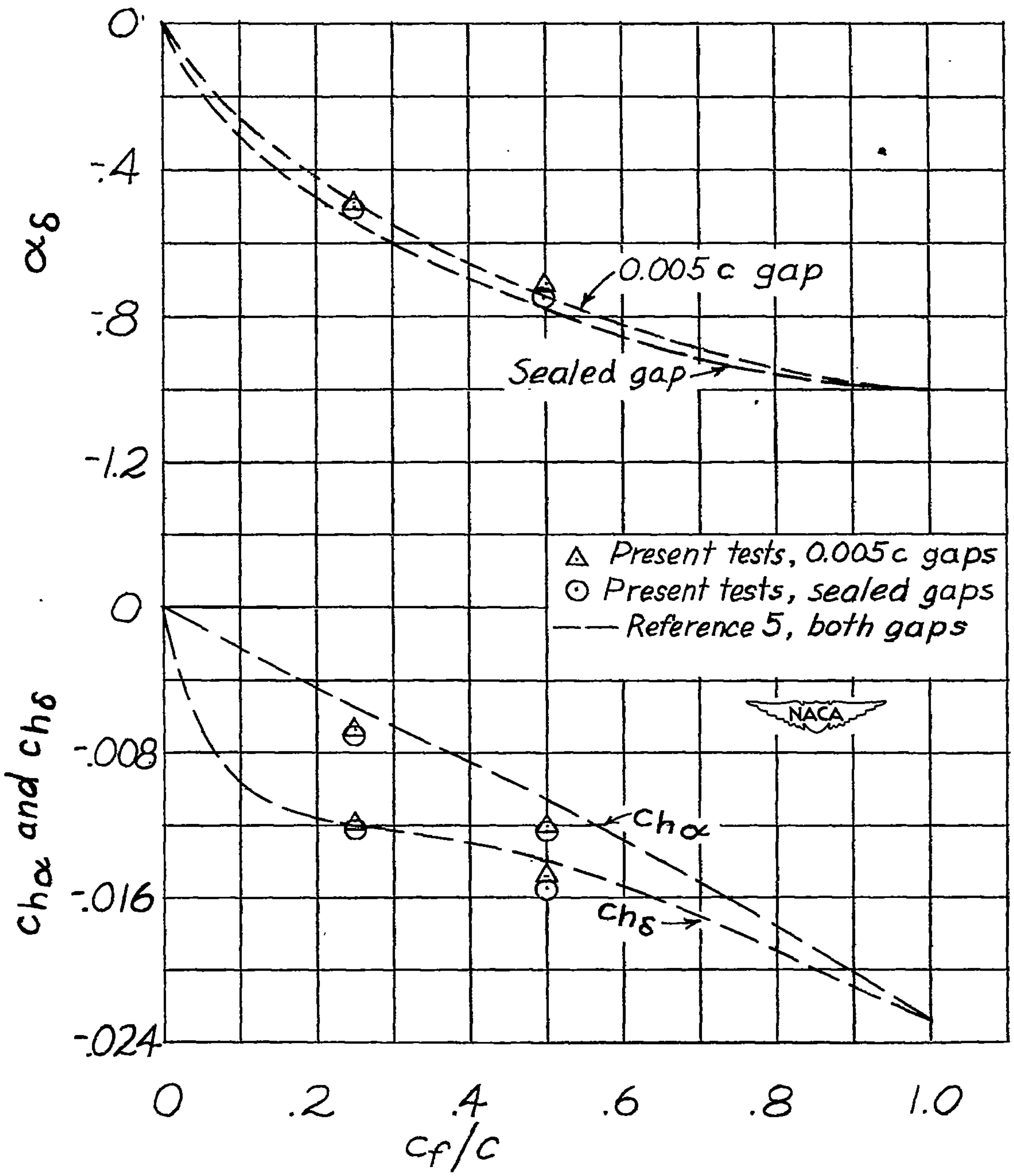


Figure 6.- Variation of lift-effectiveness and flap section hinge-moment parameters with ratio of flap chord to airfoil chord. Curves from reference 5 for plain flaps on NACA 0009 airfoil.

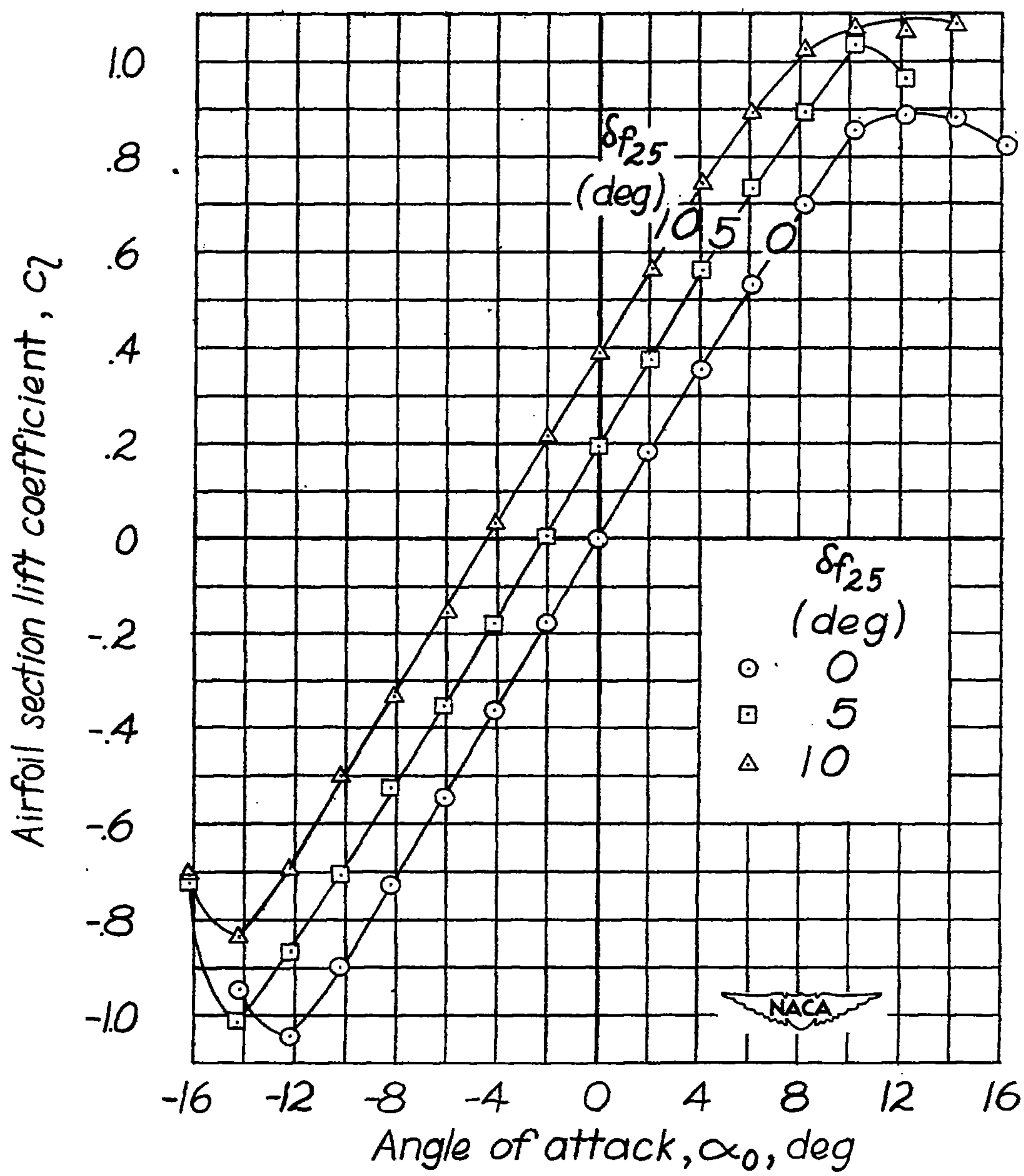
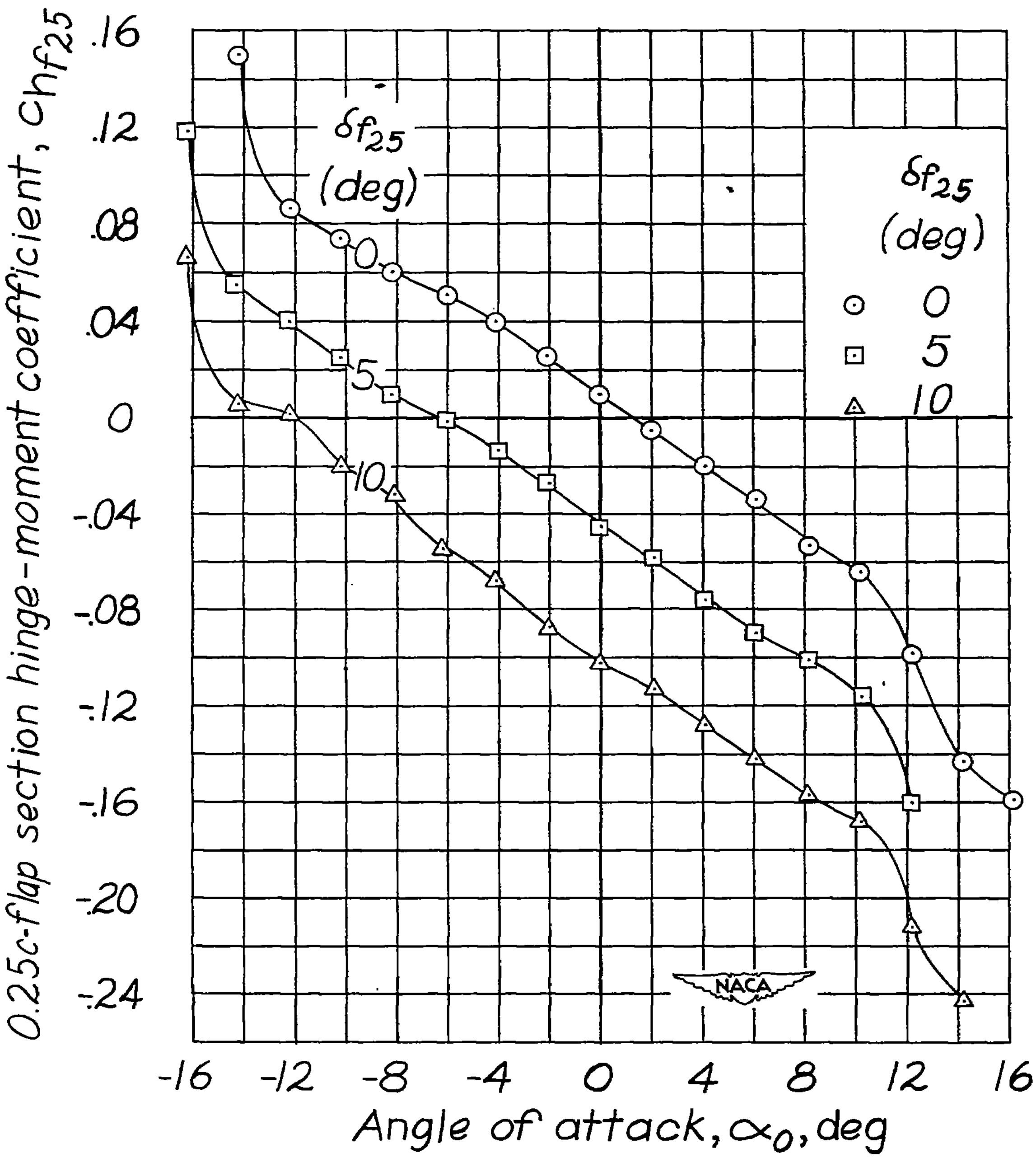


Figure 7.- Effect of deflecting the 0.25c flap on the aerodynamic section characteristics of an NACA 0009 airfoil having a 0.25c and a 0.50c plain flap. $\delta_{f_{50}} = 0°$; gaps, 0.005c.



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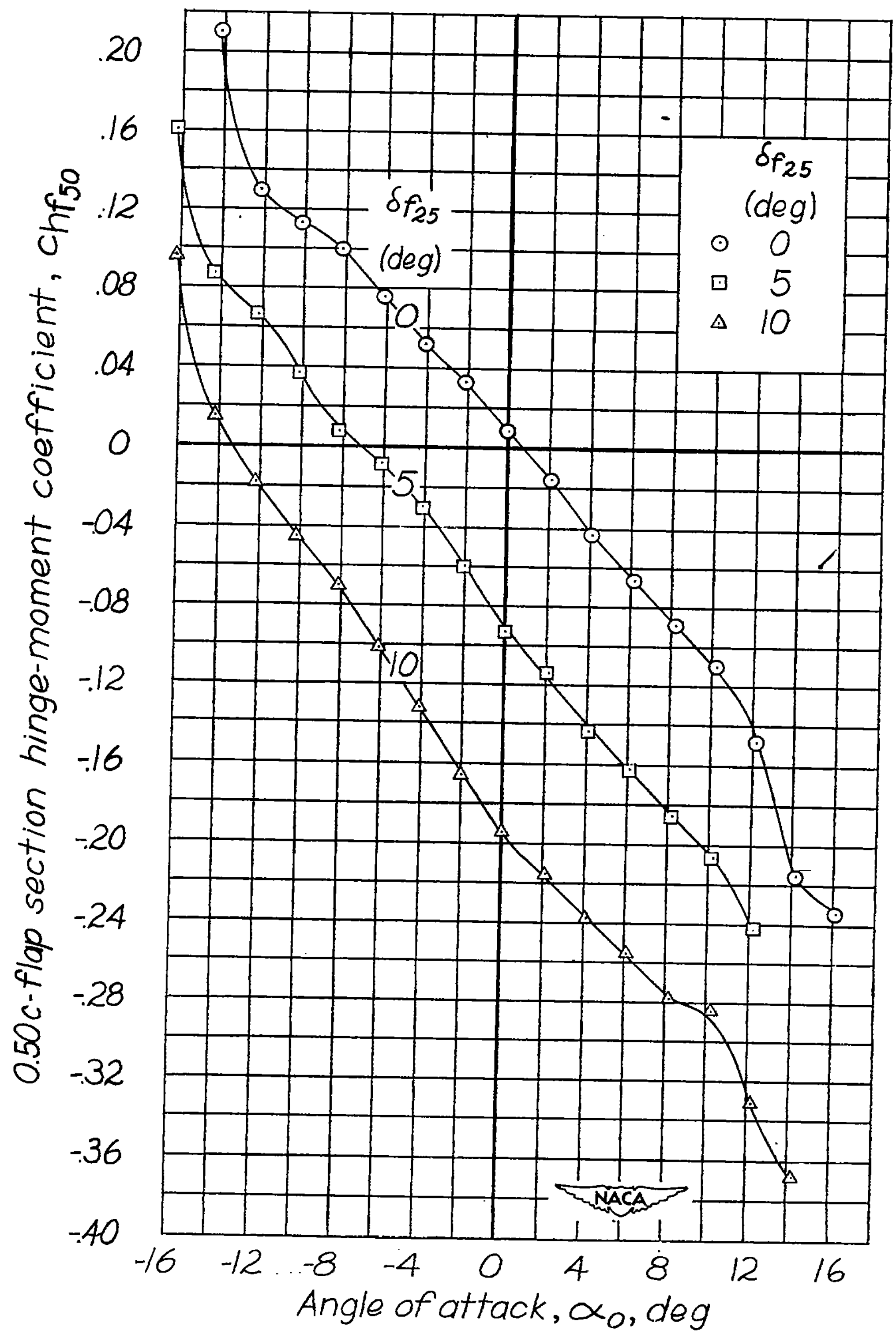

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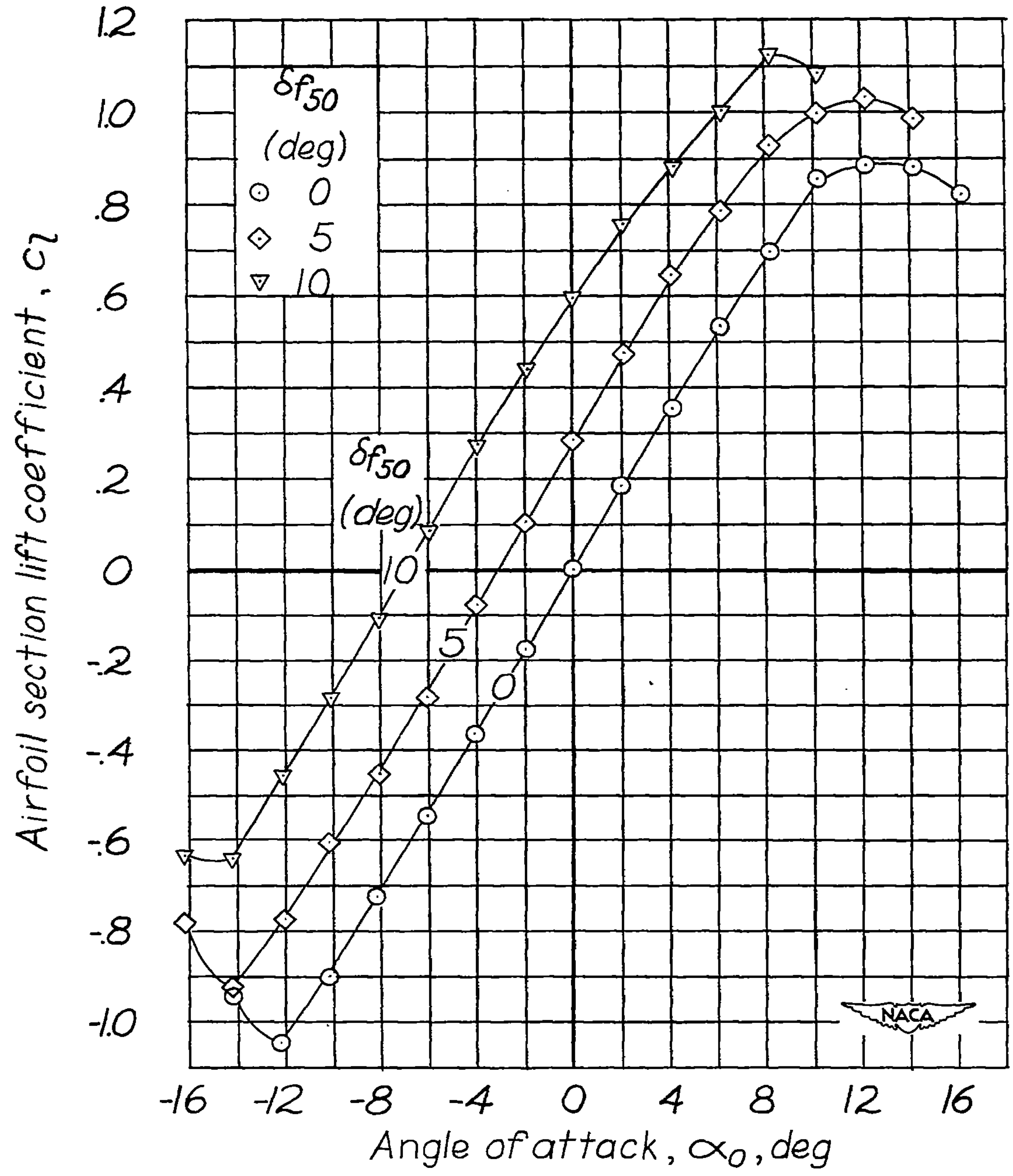


Figure 8.- Effect of deflecting the 0.50c flap on the aerodynamic section characteristics of an NACA 0009 airfoil having a 0.25c and a 0.50c plain flap. $\delta_{f_{25}} = 0°$; gaps, 0.005c.

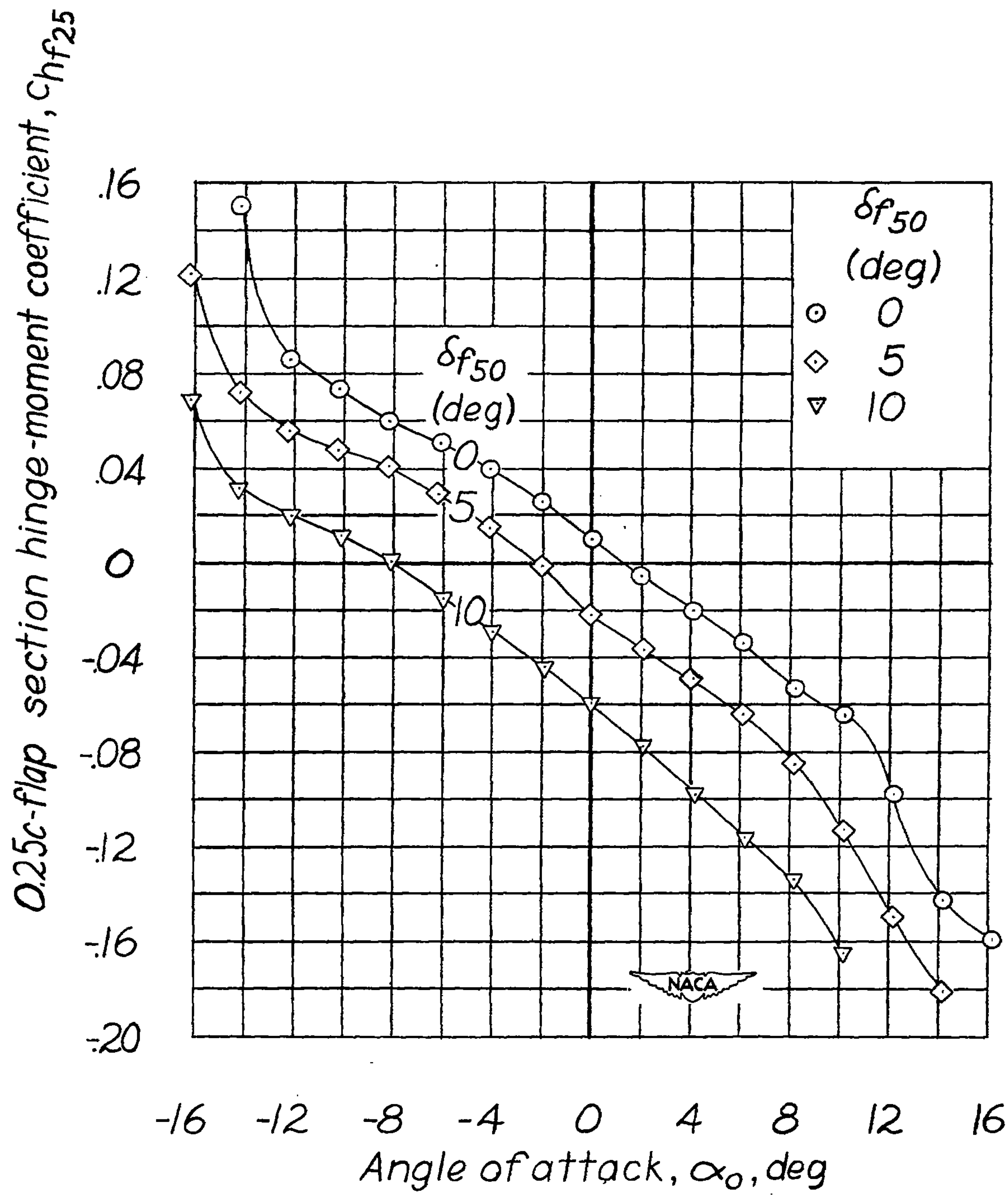
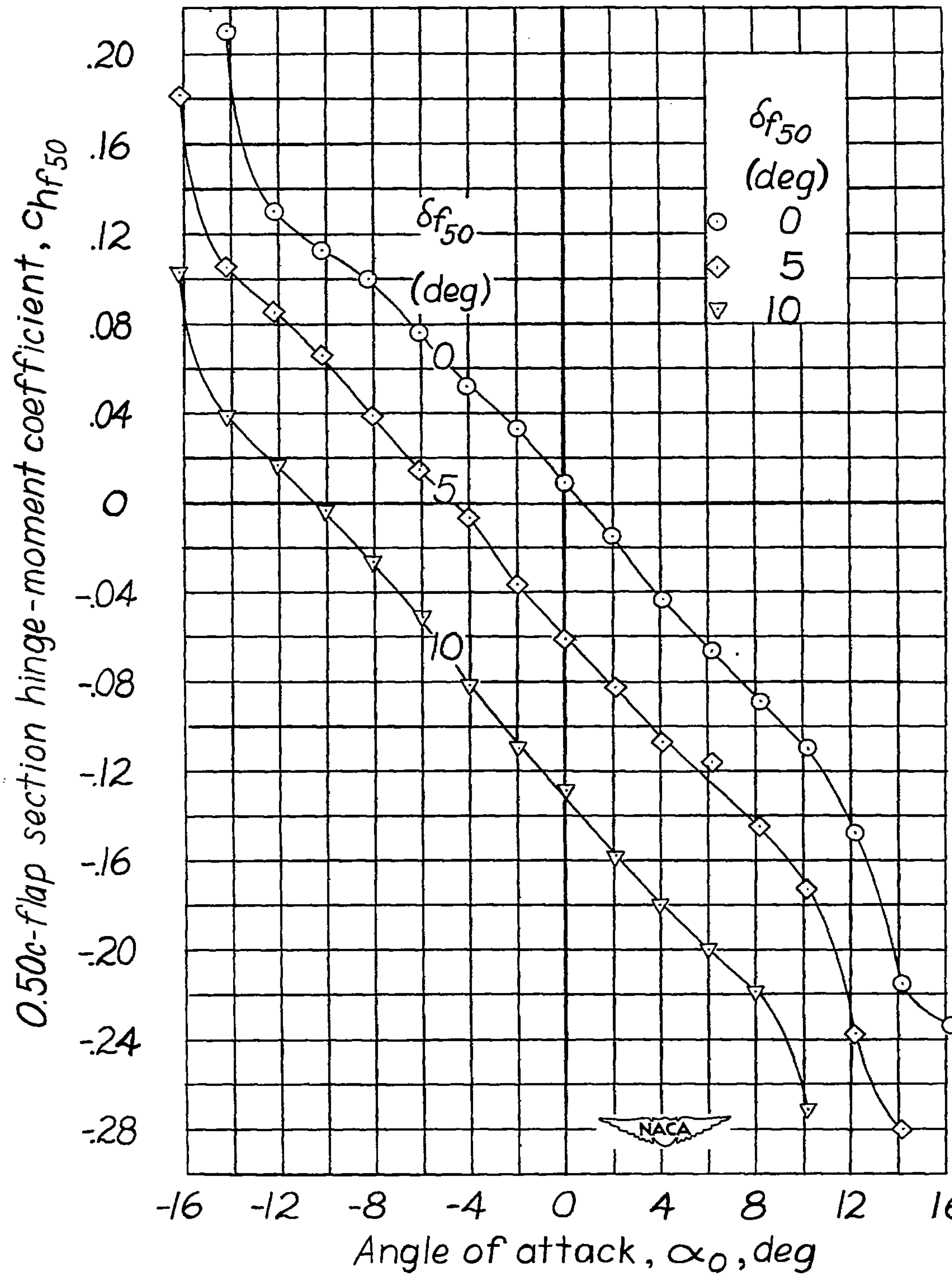


Figure 8 .- Continued .



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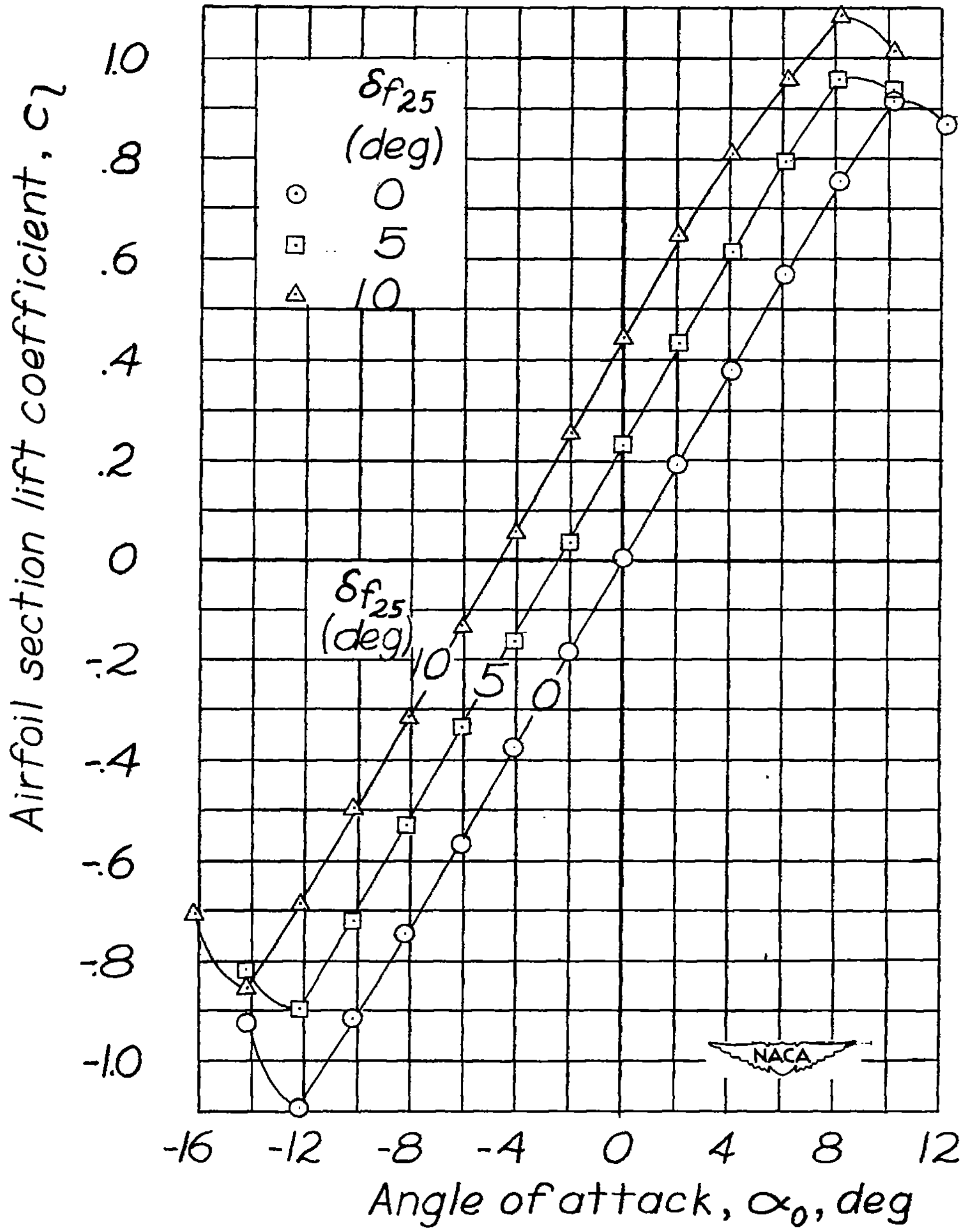

Figure 9.- Effect of deflecting the 0.25c flap on the aerodynamic section characteristics of an NACA 0009 airfoil having a 0.25c and a 0.50c plain flap. $\delta_{f_{50}} = 0°$; gaps, sealed.

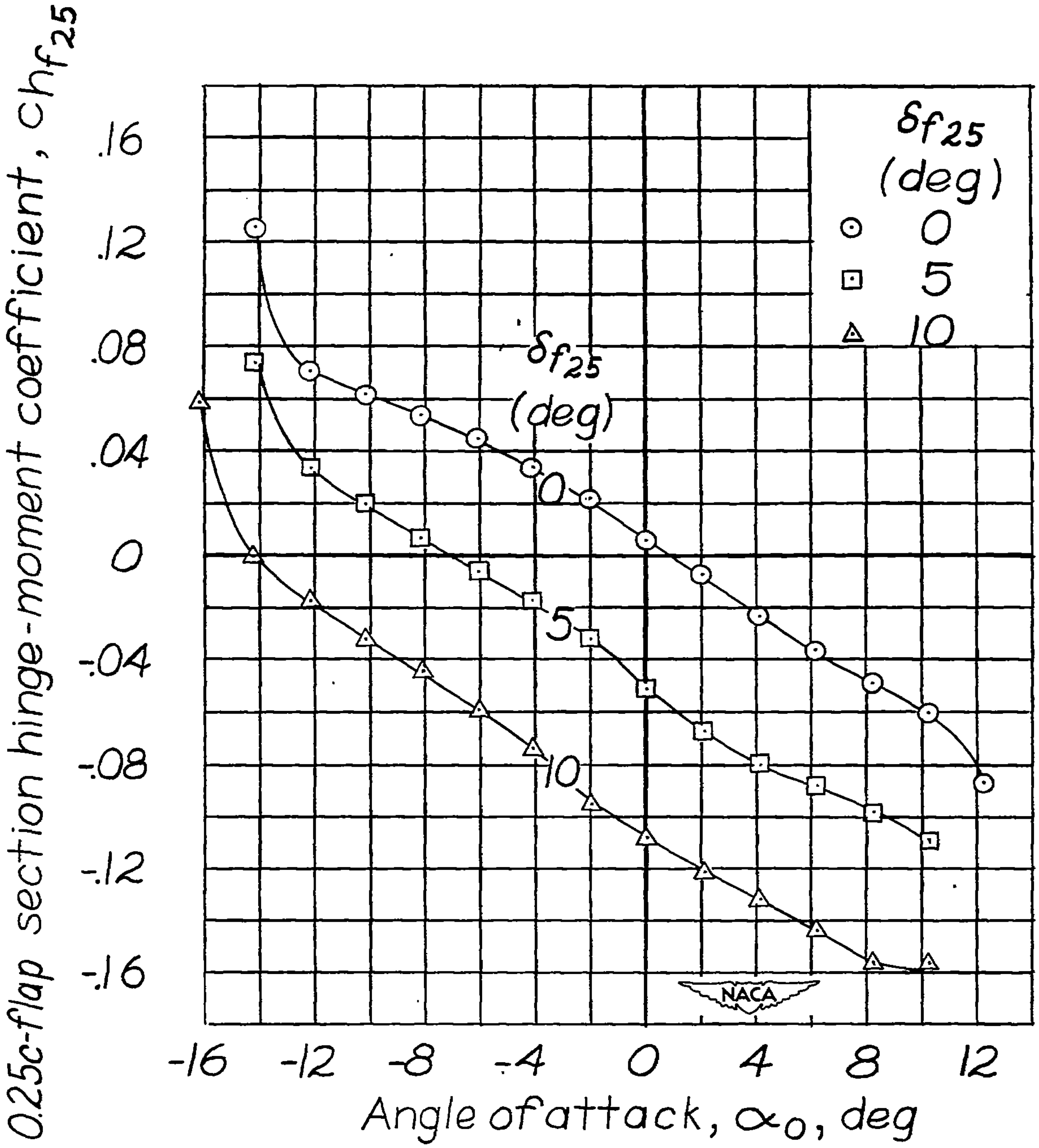

Figure 9.- Continued.

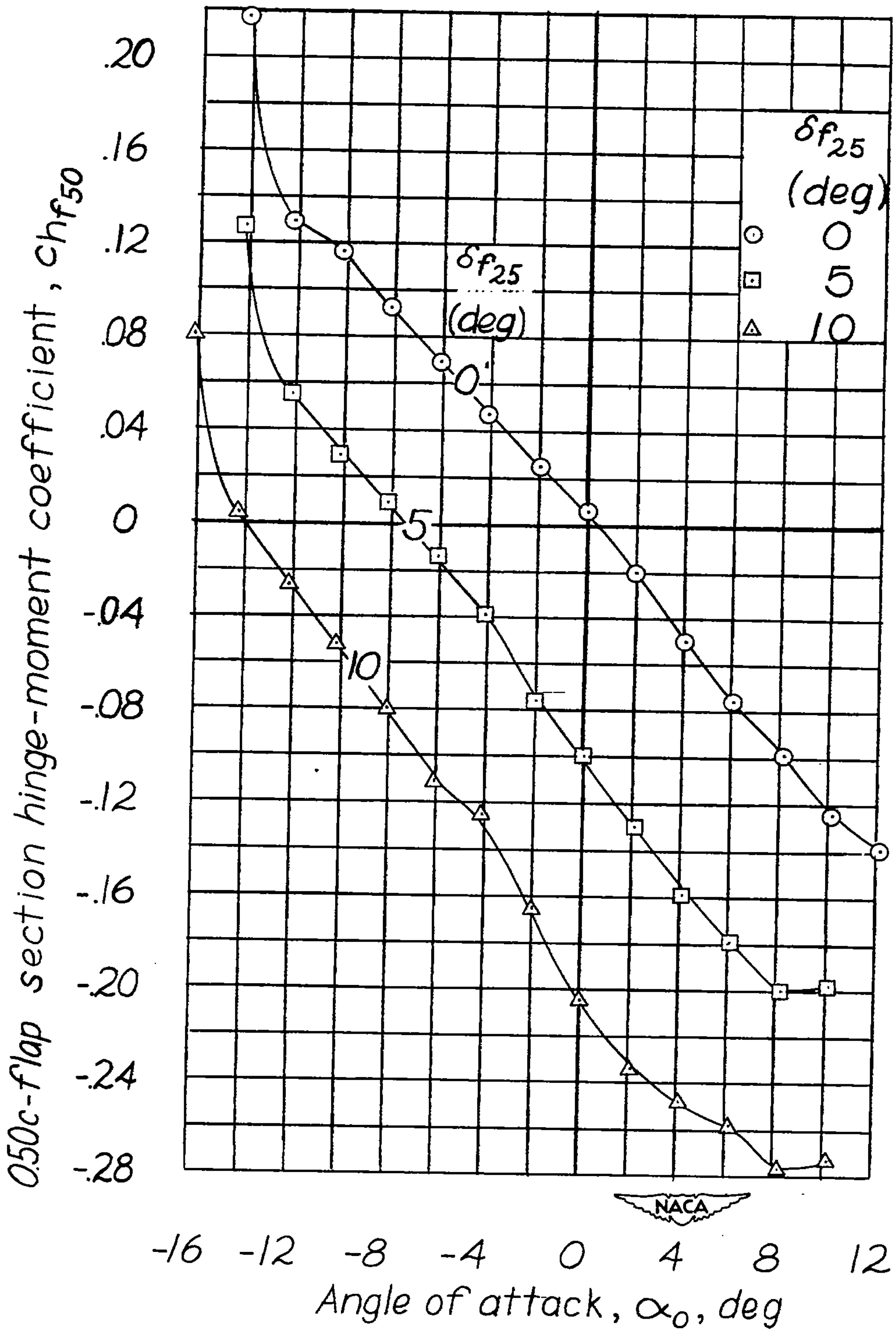

Figure 9 .- Concluded.

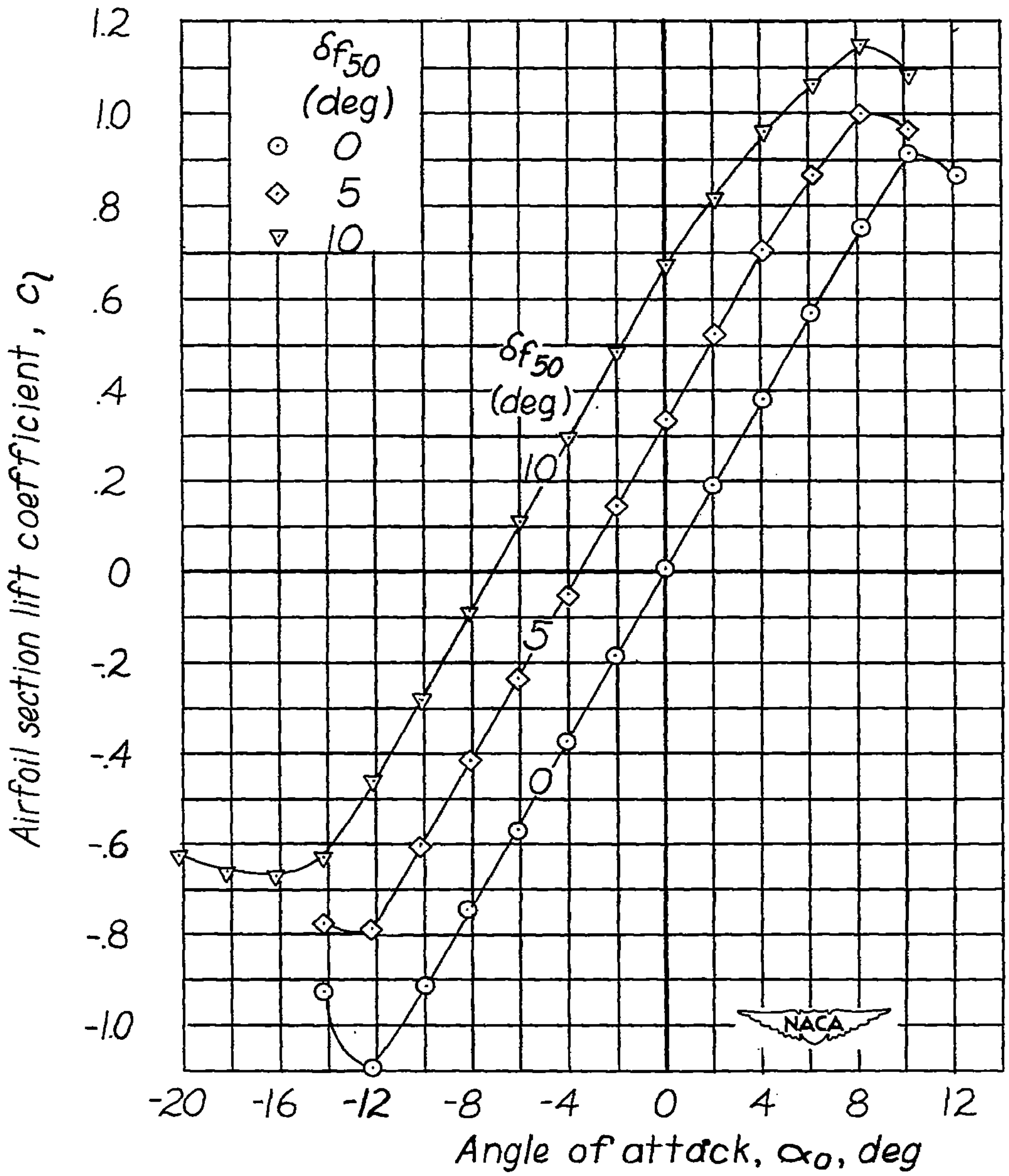

Figure 10.- Effect of deflecting the 0.50c flap on the aerodynamic section characteristics of an NACA 0009 airfoil having a 0.25c and a 0.50c plain flap. $\delta_{f_{25}} = 0°$; gaps, sealed.

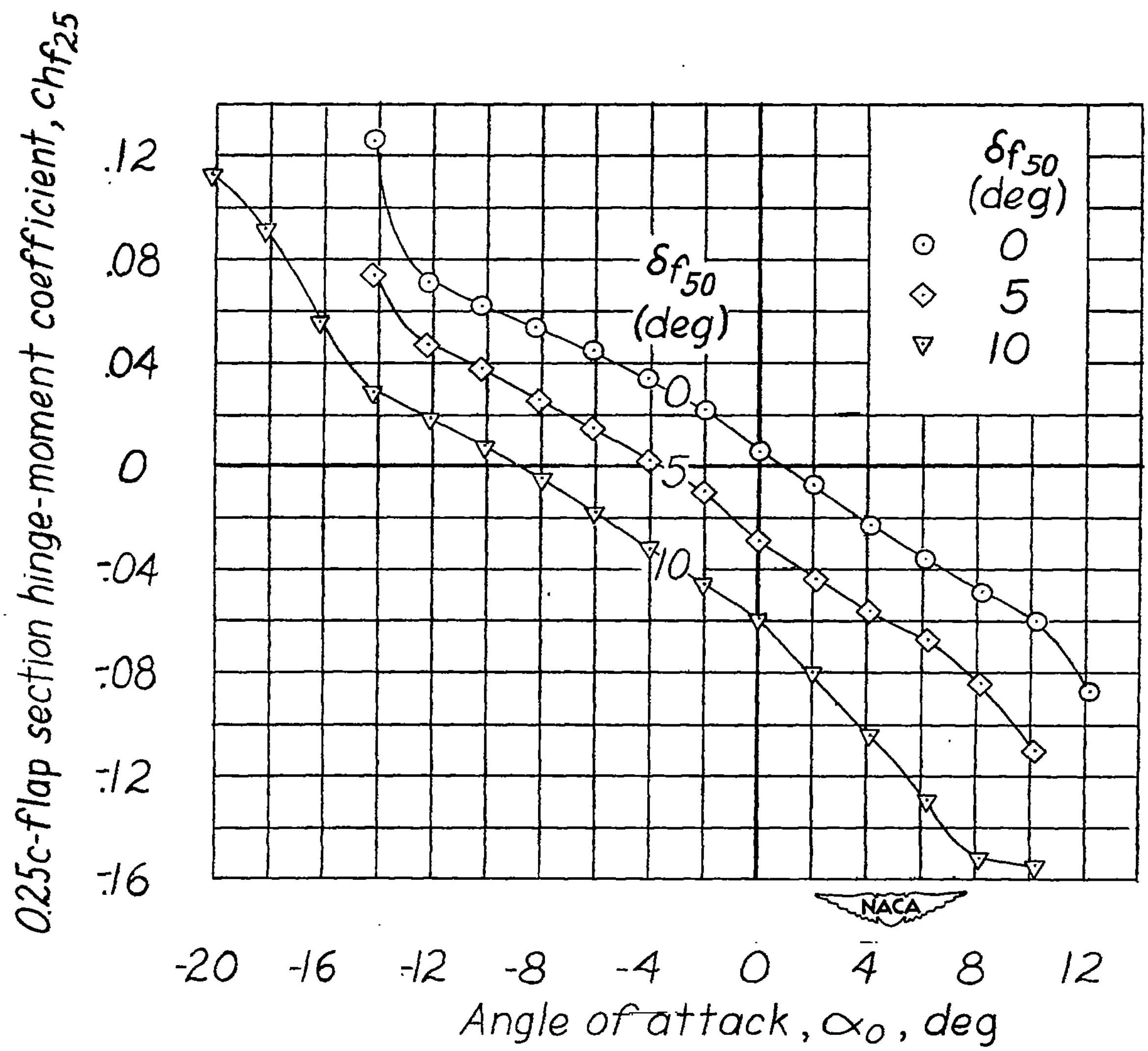

Figure 10.- Continued.

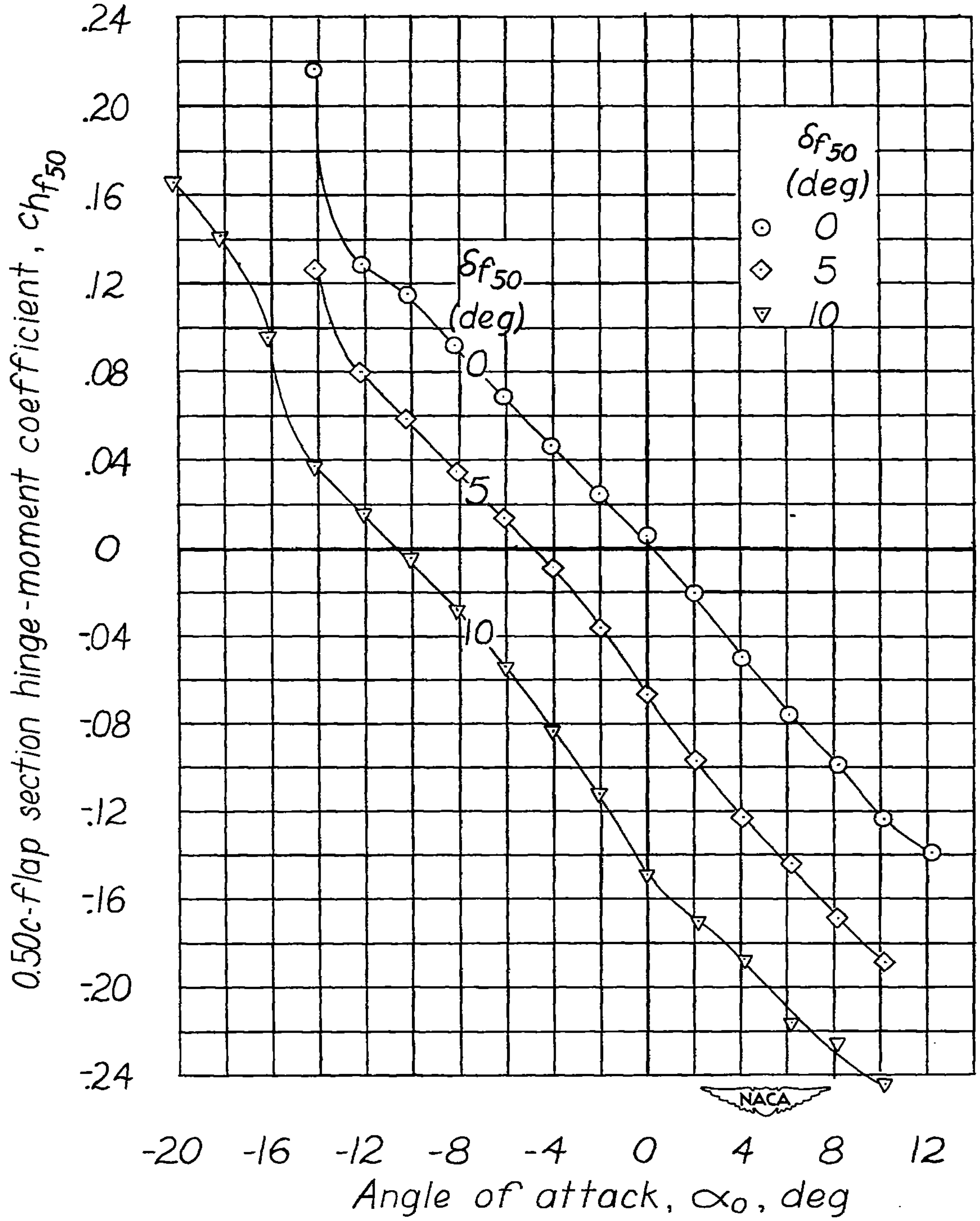

Figure 10. - Concluded.

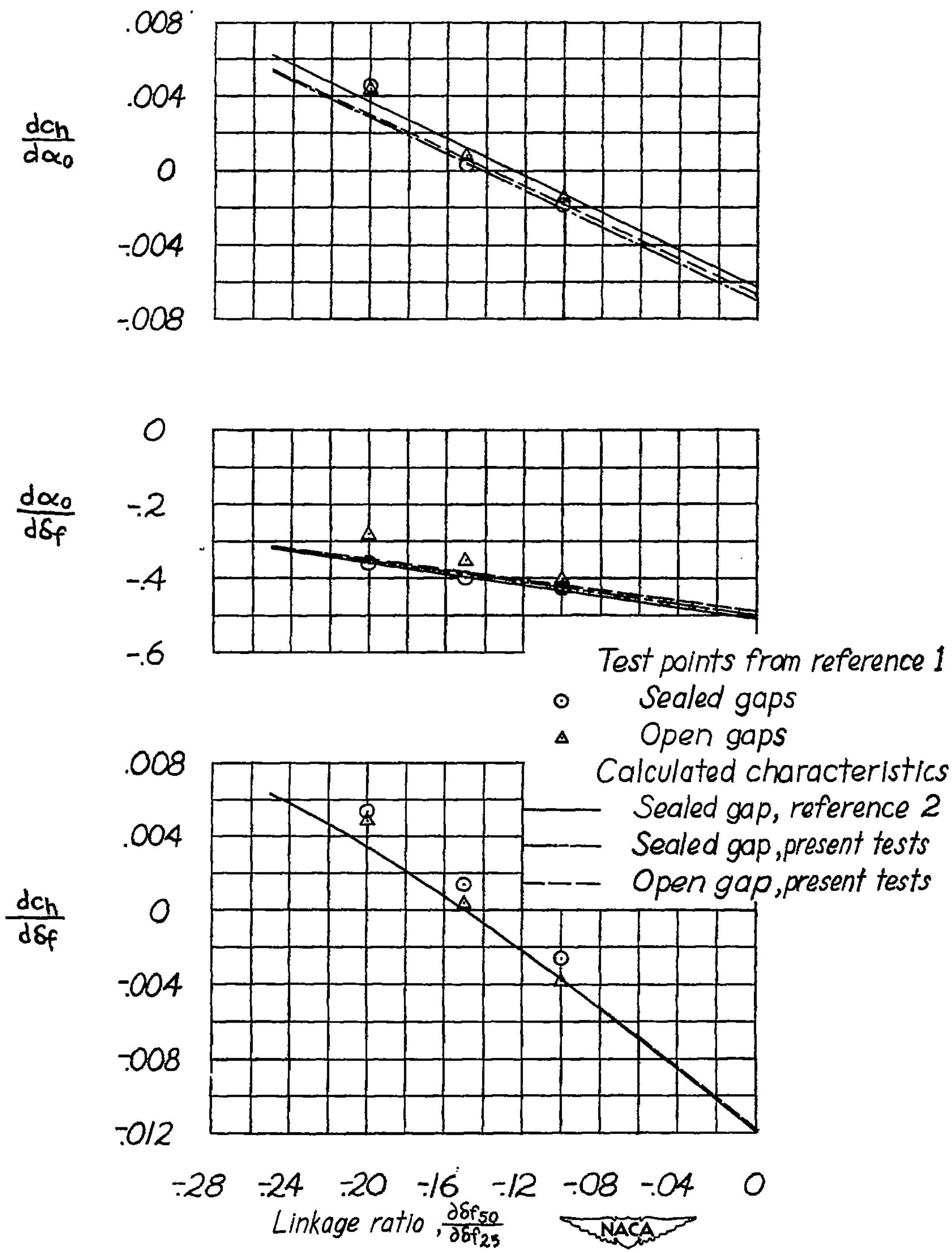

Figure 11.-Comparison of the aerodynamic characteristics of an NACA 0009 airfoil with a 0.25c control flap and a 0.50c trim flap obtained from experiment and from theory.